A Perfect Climate for PV

Of late, the news has abounded with debates. Debates on global warming, on greenhouse gases, on climate change. And on occasion, the discussion turns to a topic that we in the photovoltaics community love to broadcast: the tremendous benefits to be gained by increasing our use of renewable-energy sources such as PV.

What **we** have known for quite awhile is perhaps just beginning to dawn on those outside our community. PV is not just a novelty to be toyed with as a scientific plaything. Rather, this critical technology can provide needed power in the United States and elsewhere, while helping to build economies and protect our environment.

At the National Renewable Energy Laboratory, we are proud to be involved in the basic and applied research and development that continues to move PV into the mix of power sources. The technical results presented by NREL researchers and others at this fall's 26th IEEE PV Specialists Conference highlighted the advances we're making.

Furthermore, capabilities such as those found at NREL's Outdoor Test Facility help the manufacturing industry develop modules and systems that will stand up to real-world conditions. Such rigorous testing, coupled with standards and codes work, will lead to more PV products that are officially listed by accredited testing groups.

And as the President's Million Solar Roofs Initiative gains momentum, more and more communities throughout our nation will seek ways to make PV-generated power a reality here and now. As you can clearly see, the climate is right for the success of PV.

NREL PV

Working With Industry

Fall 1997

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The View from Space Shows Bright Prospects for PV

An Editorial by Richard Truly

Richard Truly has been a test pilot, Navy admiral, NASA Administrator, Director of the Georgia Tech Research Institute, and is now Director of the National Renewable Energy Laboratory.

It's easy to take the sun for granted. From a spacecraft, however, you gain a special perspective about the sun and our dependence on it. In particular, you realize how ideal PV modules are as a power source for satellites—lightweight, long-lasting, needing no fuel, and emitting no wastes. These attributes are particularly valuable in space. But looking down, you also see how much of the Earth is bathed in sunlight and the tremendous potential for PV to contribute to meeting our energy needs.

Then you think about how vulnerable we are to adverse impacts from the sun. Without capsule shielding or the ozone layer, ultraviolet radiation can cause severe damage. If greenhouse gases such as carbon dioxide hold in more heat, the Earth's climate can change dramatically. Which, of course, brings us back to the beauty of using PV or other renewable-energy technologies to offset greenhouse gases emitted from the burning of fossil fuels.

I'm privileged to be leading NREL into the 21st century and working with our industry partners—you who are building a thriving PV industry. At NREL, we do cutting-edge research on technologies that can alleviate many of our worst resource problems—pollution, greenhouse gas emissions, dependence on foreign oil—without sacrifice. And you are using our R&D support to turn one of the most important of those technologies—photovoltaics—into reliable, affordable, attractive products sold in the United States and globally.

We value our science, but we also value assisting you make PV technology a reality—through measurement and characterization, outdoor testing, resource analysis, new-materials and performance analysis, and quality-control technologies. Together, we are helping PV become a significant American industry that makes life better for everyone.

Now is a particularly exciting time to be working with PV and other renewable-energy technologies. The political world and the general public are rapidly gaining an appreciation of what we're doing. With the recent Kyoto climate-change summit and three major national studies under our belts, we are beginning to give global warming the attention it deserves, making commitments to do something about it, and recognizing that renewable energy is a big part of the solution. The President's Million Solar Roofs Initiative promises to provide a tangible, highly visible PV-based system of distributed electrical generation, which is designed to give a shot in the arm to U.S. markets.

NREL's PV program is a top priority for the Department of Energy and for me. We've been working with DOE and my counterparts at Sandia National Laboratories to select a permanent director for the National Center for Photovoltaics, which encompasses programs at both national laboratories. I enjoyed meeting many of you at the NCPV workshop in July, and I look forward to meeting many more of you in this new year, building fruitful relationships that focus on the success of PV.

PV Websites

NREL Photovoltaics .....http://www.nrel.gov/pv
What's PV? • Info • PV News • Partnerships • Research Projects • Facilities

DOE PV Program .....http://www.eren.doe.gov/pv
About Photovoltaics • News & Information • About Our Program

National Center for Photovoltaics .....http://www.nrel.gov/ncpv
DOE PV • NREL PV • Sandia PV • IEEE Papers

Basic Sciences & Materials.....http://www.nrel.gov/basicsciences
Materials Science • Biotechnology • Photoconversion

Measurements & Characterization...http://www.nrel.gov/measurements
Capabilities • Doing Business • Data Sharing • The Center

Renewable Resource Data Center.....http://rredc.nrel.gov
General Information • Information by Resource (Biomass/Solar/Wind)

Million Solar Roofs .....http://www.eren.doe.gov/millionroofs
Projected Accomplishments • The Program • Solar Energy Technologies

Durability Drives Research on Materials and Devices

Critically important to many high-tech industries is how engineered materials and devices will perform over time in a real-world, outdoor environment. In the electronics, aerospace, and automotive industries, for example, such durability data are extremely valuable—especially considering the economic implications of guaranteed service lifetimes and warranties associated with many of today's advanced technologies and products.

This interest was highlighted in the recent international symposium "A Systems Approach to the Service Life Prediction of Organic Coatings," held in Breckenridge, CO, in September. Technical experts representing diverse groups—DuPont, Ford Motor Company, Fraunhofer Institute, NREL, Forest Products Labs, Washington State University, and many others—discussed materials durability, accelerated testing, characterization procedures, and R&D projects.

NREL Tests in a Range of Climates

With eight outdoor test sites in the United States and Europe, NREL's National Center for Photovoltaics (NCPV) tests material and device performance under a diverse range of real-world environmental conditions. NREL's test site in Golden, Colorado, is also greatly augmented by a variety of advanced outdoor exposure test capabilities, including the Outdoor Test Facility and the High-Flux Solar Furnace.

In a typical testing program, identical samples of the material being studied are installed at each site, where they are exposed to the ambient climatic conditions for one year or longer. Before testing begins, NCPV researchers characterize the test sample extensively using state-of-the-art laboratory techniques and equipment. This initial characterization provides a baseline for understanding key performance characteristics such as construction, optical performance, power generation, and efficiency. Periodically, test samples are sent back to the lab to be measured again for performance characteristics. By comparing data from each site over time, researchers isolate the effects of relevant environmental stresses on a sample's durability.

More than 100 devices—electrochromic windows, PV cells and modules, solar mirrors, glazings, and absorber coatings—are currently being tested at each site.

An Integrated Approach

Outdoor test sites are part of a larger testing capability that encompasses sample preparation, characterization, accelerated testing, and analysis. For example, the NCPV's accelerated testing laboratories complement the outdoor sites: the effects of time-dependent stresses can be more easily studied and devices can be subjected to severe environmental mechanical stresses in a controlled environment. Using environmental chambers, weatherometers, and solar simulators, researchers isolate and identify important stress factors and accelerate the weathering process, compressing years of exposure into a few months.

Predicting Service Lifetimes

By correlating the results of real-time outdoor exposure tests with the data from accelerated tests, researchers develop service lifetime predictions for test materials and devices. The correlations between the outdoor and accelerated data identify and quantify the stress and degradation factors affecting a sample. These data are then used to develop sophisticated models that estimate long-term product performance.

The results from exposure testing and modeling are of great value to many manufacturers in the coatings and electronics industry, where 20- to 30-year product lifetimes are often the goal. Accurate service lifetime predictions, which can be produced from a relatively short testing period, generate confidence in product reliability, reduce the risks associated with warranties, and accurately project life-cycle costs.

A Resource for Industry and the Research Community

The National Center for Photovoltaics' outdoor test capabilities are the result of more than 20 years of experience of testing PV devices and optical materials for the solar energy industry. With its unparalleled outdoor testing capabilities and research staff, the NCPV is eager to help industry improve the advanced materials and devices being developed for use in real-world applications.

For more information, contact Roland Hulstrom at 303-384-6420.

Warren Gretz, NREL/PIX03986

Testing samples at the Outdoor Test Facility in Golden, Colorado.

Another Strong Showing at the PVSC

Anaheim, California, means Disneyland, generally great weather—and the 26th IEEE Photovoltaic Specialists Conference (PVSC). That's where the domestic and international PV community, including some 40 members of NREL's PV-related R&D laboratories, met from September 29–October 3, 1997.

"No dramatic breakthroughs were reported," says NREL's John Benner, who served as PVSC treasurer. But to help put this seemingly negative comment in perspective, he adds, "This is the Institute of Electrical and Electronics Engineers. And as an engineering conference, we all appreciate steady progress—from materials to devices to modules to systems and even to applications. Conference goers therefore celebrated news such as the first-time manufacturing of amorphous silicon and industrial expansion by United Solar and Solarex."

Research is also progressing as several different technologies either go into or expand production—for example, ribbon silicon at Evergreen Solar and edge-defined, film-fed growth at ASE Americas. Benner compares the process to starting a diesel engine. "First, one piston pounds. Then another. And finally they're all pounding and the engine is running."

This sentiment of steady progress was echoed by others from NREL. The PVSC gathering left them impressed, after learning that the PV industry will sell more than 100 megawatts of PV products this year. Such industry expansion means that PV manufacturers will continue to hire engineers, scientists, and managers with PV expertise.

NREL's PV staff contributed to this Anaheim meeting in many ways, first and foremost by providing results of significant work that advances the under-

Taking a Closer Look

John Webb and his NREL colleagues Doug Rose, David Niles, Amy Swartzlander, Mowafak Al-Jassim, and Al Hicks brought home honors from this year's IEEE PVSC in Anaheim, California. Their poster was judged the best of 48 entries in the category for II-VI (CIGS, CdS, and CdTe) materials and devices.

A significant thrust of Webb's work at NREL involves identifying contaminants and impurities in PV devices and device materials by measuring their infrared (IR) spectra. His 20 years of NREL research experience and a well-equipped Fourier transform infrared (FTIR) spectroscopic laboratory add considerable dimension to his work. But according to Webb, "What made this poster particularly relevant is that it included results from FTIR and several other analytical techniques used at NREL, and also included both in-house samples and samples from NREL's industry partners." The poster showed that contaminants exist as small "spots" in chemical-bath-deposited (CBD) CdS films used in II-VI devices, and that the chemical nature of the contaminants varies with the device type and with the CBD method used.

Simply put, the FTIR microspectroscopic method allows researchers to examine the IR spectrum of any given spot (such as an impurity) on the sample, which is key to identifying the chemical species it contains. This is important because impurities can be detrimental to the performance of PV devices. Knowing what they are and where they are sometimes explains how they got there—which offers clues to how the techniques for fabricating the device might be altered to improve reliability or increase efficiency.

Part of Webb's investigations involves on-line computer searches of unknown spectra against NREL's impressive library of standard FTIR spectra. The library contains the IR spectra of 50,000 known substances, with the largest individual collection representing the 25,000 chemical compounds in the Aldrich/Sigma Chemical Company's database. There are also 5000 IR spectra of polymers and 1200 IR spectra of inorganic chemicals.

Webb says that an experienced spectroscopist can often identify a sample's chemical structure by simply looking at the various bands in its spectrum, but the library adds an extra edge of certainty to that interpretation. Spectral library searches are used extensively in forensics. "We don't go to court," says Webb, "but the information we provide is of similar importance to our industry partners because it enables them to make decisions about the processing of their materials and devices."

The FTIR laboratory will soon be adding new equipment with the capability to map bandgap and defect states, as well as impurities. This technique, Fourier transform photoluminescence (FT-PL) microspectroscopy, has been described in several recent NREL publications. Defects, just like impurities, can influence device performance, and both can be detected using FT-PL.

FTIR and FT-PL spectroscopy are just some of the techniques used by NREL's Measurements and Characterization laboratories. Combining FTIR with other methods (such as X-ray photoelectron and Auger electron spectroscopy) gives a detailed picture of the structure and composition of a given sample. In addition to working with NREL's PV partners, the M&C group serves in-house PV research, other NREL programs (such as thermophotovoltaics and biotechnology), and other industries.

For more information, contact John Webb at 303-384-6703.

standing of PV—from fundamental science to applied R&D, manufacturing issues, testing, applications, and market development.

Thirty-seven papers having NREL first-authors were presented, either orally or as posters, at the PVSC. This year, we are making these papers available in two forms: electronically via the Internet (at http://www.nrel.gov/ncpv/ieee.html) or in a bound, hard-copy version (contact Susan Moon, 303-384-6631).

Either form highlights the breadth of activities at the Laboratory, which cover silicon; thin-film technologies (CdTe, CIS, III-V/high-efficiency devices); module and BOS manufacturing; cell, module, and system testing; and market development.

NREL's Tim Coutts, who chaired the PVSC Auxiliary Program, commended Xuanzhi Wu's paper, Applications of Cd_2SnO_4 Transparent Conducting Oxides in CdS/CdTe Thin-Film Devices. "Cadmium stannate is a new TCO," says Coutts, "essentially pioneered by NREL, and it is being sought after by some of our subcontractors in the field of cadmium telluride solar cells."

Coutts and others also appreciated the plenary paper, Current Status of Polycrystalline Thin-Film PV Technologies, by NREL's Harin Ullal. Ullal provided an excellent whirlwind review of the field of polycrystalline thin-film solar cells, including a global perspective and R&D issues.

Besides presenting findings from the Laboratory's R&D centers, NREL scientists participated in the various national meetings held in conjunction with the PVSC. For example, The National CdTe and CIS R&D Teams met to discuss the progress of the various teaming activities. About 60 people representing academia, NREL, NASA and the thin-film PV industry attended the meetings. The CIS National Team reported on the role of CdS, the direct contacting of ZnO/CIS, the role of Na, and transient-effect studies. The CdTe Team focused on the stability of solar cells, various approaches to modeling of devices, and the role of TiO_2 in a device structure.

The newly established PV Concentrator Alliance met for the first time since its founding last spring, with solid participation from manufacturers of PV concentrators and components and from NREL, SNL, and DOE. Cecile Warner presented the newest solar resource modeling and mapping capabilities at NREL—activities that attracted strong support from the Alliance participants.

Manufacturers, system integrators, and representatives from DOE, NREL, and SNL also gathered for the Industry Forum of Manufacturing-Related Issues for Balance of Systems, Systems, System Integration, and Storage. They discussed issues critical to industry success, with an eye toward finding areas where companies could better collaborate.

Sessions sponsored by the PVSC's Auxiliary Programs highlighted PV in Developing Countries, PV on Buildings, and a lunchtime speaker (Geoffry Landis, who worked at SERI/NREL 10 years ago before beginning a career in space PV) discussing the Mars Lander mission. NREL's Larry Kazmerski and Cecile Warner co-directed the High School PV Design Project Competition. Nine teams, including more than 50 students and mentors from high schools throughout Orange County, California, designed, built, and presented practical PV projects, using solar cells as the only means of power. This year's first-place team, Los Alamitos High School, had a three-part project on PV and traffic safety.

So, all things considered, the PVSC affirmed that the U.S. PV industry is pounding on all cylinders. Maintaining, and even extending, the U.S. technology lead continues to be the focus of NREL and our many industry partners who attended this year's conference.

For more information, contact Susan Moon at 303-384-6631.

Lester Lefkowitz, Tech Photo, Inc./PIX04822

John Webb, a senior scientist at NREL, at work at his FTIR microscope. This instrument allows researchers to map the chemical bonds of small areas or spots in the sample, an important step in improving the performance of PV materials and devices.

An Inside Look at the Million

Christy Herig, NREL/PIX05650

Christy Herig is optimistic about the growth of PV markets through the Million Solar Roofs Initiative.

Do one million solar installations in the United States by 2010 sound out of reach? Not after talking to NREL's Christy Herig.

Christy Herig has been with NREL for almost 3 years as a senior engineer working on markets, utilities, and policy. Prior to that, she spent 15 years with Florida Power Corporation in St. Petersburg, Florida. Herig works closely with Carol Tombari, also from NREL, who is charged with coordinating all national-laboratory support for the Million Solar Roofs Initiative (see box to right). Howard Wenger and Tom Hoff of Pacific Energy Group, Richard Perez of the State University of New York, and Tom Starrs, a legal-policy consultant, have all contributed to the work described below.

What's the focus of your activities at NREL?

My overall strategy is to take a comprehensive look at markets for PV as the industry moves into commercialization and large-scale deployment. I started by looking at utilities and their financials and how adding renewable energy investments to their portfolios might improve customer satisfaction. I've also been looking at states and how they might build some renewables investments into their deregulation-related restructuring packages. California was faced with spending $34 billion to reduce the debt from fossil- and nuclear- energy expenditures, which, of course, the constituency hated. But state leaders softened the blow by making a phenomenal, nearly $1 billion investment in renewables.

How does your work relate to Million Roofs?

I or a colleague might be asked to look at legislation favorable to renewables in a state's restructuring package, and evaluate its potential for state economic development and revenue impacts. Typically, time is of the essence, so we might do a quick spreadsheet analysis that goes something like this: You've got this much constituency and these are your electric rates, so this is the revenue impact. In this way, we helped support the development of the Arizona Solar Portfolio Standard, the Nevada Portfolio Standard, and the California Assembly Bill 1890. We also worked to extend the sunset on Hawaii's personal income-tax incentives related to solar technologies.

Some of this work involves a broader base, such as our analysis of customer-sited PV niche markets on a state-by-state basis, focusing on a bottom-line cost to the consumer. We discovered that some geographical areas are close to being cost effective for PV right now—so let's target them. Then we dug deeper and found that what makes them cost effective are policies. And a big part of Million Roofs involves taking advantage of existing policies, tax incentives, and loan packages—and encouraging the development of new ones. California is doing some capital buy-downs, for up to 45% percent of the cost, which will bring PV into the range of approximately $3 a watt.

Have you seen any interesting developments lately?

Yes, and this one will turn the community of Tampa, Florida, into a PV showcase. One of the

News at Press Time

IEC Elects New TC-82 Chairman

Richard DeBlasio has been elected as the next **International Electrotechnical Commission (IEC)** TC-82 chairman for PV Solar Technology international standards development. He will succeed Professor Y. Sekine of Japan. IEC General Secretary A.M. Raeburn recently informed DeBlasio of the election results of the IEC member countries (Australia, Austria, Canada, China, Czechoslovakia, Denmark, France, Germany, India, Italy, Japan, Romania, Russia, Spain, Switzerland, and United States). Technical Committee 82 has developed more than 20 IEC PV international standards and has four working groups—to be expanded to seven groups to meet the growing demand for component- and system-level PV international standards. These standards will be used in accreditation and certification programs worldwide. Contact: **Dick DeBlasio, 303-384-6452**

Zunger Wins DOE-BES Award

Dr. Alex Zunger, Research Fellow and head of the Basic Sciences Center's **Solid State Theory Team** at NREL, has won the 1997 Department of Energy-Office of Basic Energy Sciences award for "Sustained Outstanding Research in Solid State Physics." This is the first time that NREL has won this award in the 15 years of its liaison with DOE-BES. The citation is for Zunger's work on "Prediction of Novel Ordered Intermetallic Compounds and their Properties," which involved developing the methodology for predicting optical, structural, and thermodynamic properties of random and ordered alloys. This methodology was applied to metals, semiconductors, and oxides. Contact: **Satyen Deb, 303-384-6405**

Solar Roofs Initiative

Tampa Bay bridges needs to be replaced, and the state usually takes old railroad properties and bridges and renovates them for recreational uses, such as fishing. A proposal now on the table outlines a plan to cover the bridge with a pavilion topped by PV panels. It would have cost $9 million to tear down the bridge—now they can do the renovation, including the PV pavilion, for $7.5 million. It's looking pretty positive that this will happen.

How do our industry partners get involved in Million Roofs?

We're seeing a lot of different leaders for Million Roofs projects come out of the woodwork. Utilities are an obvious one, but industry can do it, too. The Civano project in Tucson is a model Million Roofs example. They're planning to build an entire sustainable community with solar-powered homes, markets, offices, and parks. The Civano organizing group includes state and city leaders, a utility, and local environmentalists, builders, and solar industries. It's hard to tell who got the project started. A lot of separate entities were trying to pull it off, someone suggested they get together, and it's amazing the way they're working together. To accomplish something this big, you need a chorus, you always need a chorus!

What will it take to achieve a million installations?

It's all about pulling together different groups and individuals and zeroing in on what's valuable to them. Funny thing is, we've had these energy- type initiatives and energy-efficiency programs all along, but this is the one that pulls all those perspectives together—and it's amazing the way people are stepping up and making commitments. New England Electric System has committed to 100,000 systems. Hawaii Electric, with only 25,000 customers, is promising 12,000 systems. L.A. Water and Power District is committing to 100,000 systems. People want to participate—they're asking questions with a new kind of intensity.

Million Roofs Questions—and Answers!

Peter Dreyfuss, DOE's recently appointed coordinator of the Million Solar Roofs Initiative, developed a list of the top ten questions with regard to the Initiative. Selected highlights that should be of interest to the PV community follow. For the complete list, visit the Million Roofs Website at http://www.eren.doe.gov/millionroofs/faq.html.

What is the Million Solar Roofs Initiative?

Million Solar Roofs is an initiative to install solar energy systems on one million U.S. buildings by 2010. Announced by President Clinton on June 26, 1997, the Initiative includes two types of solar technology: photovoltaics and solar thermal.

What are the qualifications for a building to be a part of this Initiative?

A building's solar energy system must comply with all relevant parts of the National Electrical Code, Underwriters Laboratories standards, and the Solar Rating and Certification Corporation standards. The system must also be located on or immediately adjacent to the building and, for PV systems, must meet the following minimum standards: residential systems, 0.5 kW; commercial systems, 2.0 kW.

Who is a Million Solar Roofs Partner?

Solar energy equipment manufacturers and distributors are included among the potential national partners. Any person or organization who installs the minimum-size PV or solar thermal energy system on a residential, commercial, institutional, or government building will be able to register with the Million Solar Roofs Registry.

What is the Federal commitment with its own buildings?

The Federal sector represents about 0.5% of the U.S. building inventory with its 500,000 buildings. President Clinton has committed the Federal government to install PV and solar thermal energy systems on 20,000 Federal buildings by 2010. DOE's Federal Energy Management Program will assist Federal agencies to meet that commitment.

Director Truly Reorganizes NREL

In September, NREL's director, Admiral Richard Truly, realigned the Laboratory's organizational structure. Of greatest importance to the photovoltaics community is the formation of NREL's **National Center for Photovoltaics** through the merger of the Center for PV and Electronic Materials, the Center for Measurements and Characterization, and the Center for Performance Engineering and Reliability. **Roland Hulstrom**, who previously headed the last-mentioned center, was named as the deputy and acting director of the NCPV. The Center for Basic Sciences and the Center for Renewable Energy Resources remain separate from the NCPV. But both are involved in cross-cutting R&D activities that include photovoltaic research, measurements, and analysis. Two departments at Sandia National Laboratories—PV System Components (headed by Margie Tatro) and PV System Applications (headed by Chris Cameron)—continue to partner with NREL in the NCPV. Contact: **Roland Hulstrom, 303-384-6420**

Headlines for Research in NREL's Ultrafast Laser Lab

Research in **NREL's Ultrafast Laser Laboratory**, operated jointly by members of the **National Center for Photovoltaics** and **NREL's Basic Sciences Center**, gained national attention for NREL's world-class capabilities in measuring and characterizing PV semiconductors. *Laser Focus World*, a national magazine specializing in optics, electro-optics, and optoelectronics, featured an eye-catching photo from the Ultrafast Laser Laboratory on the cover of its October 1997 issue. The cover photo is a lead-in for an article about recent advances in ultrafast lasers used for pump/probe spectroscopy. Members of the NCPV's Laboratory for Measurements and Characterization use the unique capabilities of the Ultrafast Laser Lab to investigate fundamental physical processes in thin-film CdTe/CdS solar cells. These studies increase the likelihood of near- and far-term gains in efficiency by increasing the PV community's understanding of the materials and devices used in photovoltaics. Contact: **Dean Levi, 303-384-6605; Angelo Mascarenas, 303-384-6608**.

NREL PV researchers and managers interact with industry on several levels. Although we freely share our research results and the nonproprietary results of our subcontractors, many of our interactions involve the exchange of confidential information, including the results of certain measurements. The following are some notable recent interactions.

The EPRI/DOE Photovoltaic Application Experience Workshop, held in Denver, CO, on August 25-26, was organized by **Frank Goodman (EPRI)** to review PV applications and experience, identify problem areas, and identify opportunities for cooperation and collaboration to address the needs. **Holly Thomas (NREL)** moderated the session on Interconnection and Safety, and **Dick DeBlasio (NREL)** provided additional comments on testing, standards, certification, and product definition. Results of this workshop were summarized in an EPRI report "PV Application Experience Workshop Results," Sept. 1997, by Frank Goodman. The 27 attendees—from utilities, module manufacturers, system integrators, **EPA**, **WAPA**, **UPVG**, **NREL**, and **SNL**—were encouraged to take the information to their respective organizations and apply it as appropriate. Key issues, their relative priority, and who should be taking a leadership role in resolving them were identified for the topics of Interconnection and Safety, PV Products, Operating Requirements, and Project Planning, Procurement and Installation. Contact: **Holly Thomas, 303-384-6400**

On September 12, 1997, **ASE Americas** held a formal ground breaking for its facility in Billerica, MA, which expands their silicon wafer production by their proprietary EFG technology. More than 100 people participated in the ceremonies, which focused on the themes of sustainability and cooperation. The invitees included **Congressman M. Meehan**, **D. Reicher and A. Hoffman (DOE)**, **D. O'Connor (Massachusetts Department of Energy Resources)**, **R. Mercier (Town Manager, Billerica)**, **S. Sklar (SEIA)**, **W. Hoffman and C. Gay (ASE Americas)**, **T. Surek (NREL)**, and several industry and utility representatives. Over the last 24 years, the EFG process has been extensively studied through various research programs funded by the government (DOE and its predecessors) and corporations. The two phases of this expansion will increase ASE's wafer capacity from 4 MW to 20 MW and create 200 high-tech jobs. Contact: **Tom Surek, 303-384-6471**

NREL is measuring the photoluminescence lifetime on a series of GaAs-AlGaAs double heterostructures that **Research Triangle Institute (RTI)** prepared on Mo foil substrates. A recent best sample showed an initial decay of 0.41 ns and a secondary decay constant of about 1.5 ns. This initial decay for n-GaAs on Mo is about ten times longer than the lifetime RTI started with some 6 months ago. The results of the program on the growth of high-quality GaAs materials in the presence of grain boundaries are relevant to both low-cost, flat-plate cells on Mo and concentrator cells on poly-Ge. **Rama Venkatasubramanian (RTI)** and **Brian Keyes (NREL)** believe that RTI's goal of 1-2 ns is achievable, which would be a significant step in developing a poly-GaAs solar cell on low-cost substrates with a 1-sun (AM1.5) efficiency of 18%. Contact: **Brian Keyes, 303-384-6695**

NREL staff, which included **Gary Jorgensen**, **David King**, **Al Czanderna**, **Daryl Myers**, and **Roland Hulstrom**, participated in an international symposium, held in Breckenridge, CO, in September, entitled "A Systems Approach to the Service Life Prediction of Organic Coatings." NREL presented results and listened to other experts discuss materials durability, accelerated testing, characterization procedures, and R&D projects. Sixty-one technical experts attended, representing major U.S. industrial firms (**DuPont, Ford Motor Company, Shell, 3M, General Electric, Owens Corning, Monsanto, DOW Chemical**, and **Sherwin-Williams**), international R&D groups (**Swedish National Testing and Research Institute, Fraunhofer Institute, Japan Atomic Energy Research**, and others from France, the UK, Norway, Germany, Singapore, Belgium, and Switzerland), and U.S. groups (**NREL, NIST, Federal Highway Administration, the Aluminum Association, Iowa State U., Washington State U., U. of Cincinnati, U. of Colorado, the Forest Products Labs**, and the **Atlas Weathering Services Group**). Contact: **Roland Hulstrom, 303-384-6420**

Four crystalline-silicon modules from **BP Solar**, two CIS modules from **Siemens Solar Industries**, plus one amorphous-silicon module from each of **Sovlux** and **United Solar Systems Corp.**, have inaugurated an expansion of the Performance and Energy Ratings Test-bed (PERT). The electrical performance of each module will be sampled every 30 minutes during daylight hours under all prevailing conditions. Their power and energy production capacities will be assessed over the upcoming months and years. This information will feed into an energy-ratings methodology being developed at **NREL**. Contact: **Joe del Cueto, 303-384-6104**

More than 30 industry representatives for **PV manufacturers and system integrators** attended a forum for industry organized in conjunction with the 26th IEEE PV Specialists Conference in Anaheim CA. The forum was co-chaired by **Holly Thomas (NREL)** and **Ward Bower (SNL)**. The purpose was to discuss industry issues to determine if there is a consensus on areas where companies could work together. The six major headings for general discussion by industry representatives were: 1) Million Roofs and long-term perspective, 2) interconnection, standards, and codes, 3) storage, 4) BOS-specific issues, 5) other, and 6) need

Continued on page 11

Announcing the Awards from the Thin Film PV Partnership Recompetition

Sixty-three responses to the 2nd Thin Film PV Partnership Letter of Interest (LOI) were received by July 31, 1997. The total requested funding was about $120 million (NREL/DOE share)—about 300% more than the funding levels expected during the LOI's 3-year period. The responses were reviewed by NREL and external reviewers from universities, EPRI, and other national laboratories.

The following tables summarize—in alphabetical order and by award type and thin-film technology—the 33 PV companies and universities that are potential awardees. Levels of funding, not yet determined, will depend on DOE funding availability. The majority of awards are scheduled to begin in the first quarter of 1998. Contact: **Ken Zweibel, 303-384-6441**

Technology Partner Proposals
- AstroPower (Newark, DE)
- BP Solar (Fairfield, CA)
- Energy Photovoltaics, Inc. (Princeton, NJ)
- Global Solar Energy (Tucson, AZ)
- Optical Coatings Laboratory, Inc. (Santa Rosa, CA)
- Siemens Solar Industries (Camarillo, CA)
- Solar Cells, Inc. (Toledo, OH)
- Solarex (Newtown, PA)
- United Solar Systems Corporation (Troy, MI)

CIS R&D Partner Proposals
- Colorado State University (Fort Collins, CO)
- Daystar (Golden, CO)
- Florida Solar Energy Center (Cocoa, FL)
- International Solar Electric Technology (Inglewood, CA)
- Materials Research Group, Inc. (Wheat Ridge, CO)
- University of Florida, Gainesville (Gainesville, FL)
- Washington State University (Richland, WA)

CdTe R&D Partner Proposals
- Colorado School of Mines (Golden, CO)
- ITN (Golden, CO)
- University of South Florida (Tampa, FL)
- University of Toledo (Toledo, OH)
- Weizmann Institute (Rehovat, Israel)

a-Si R&D Partner Proposals
- Colorado School of Mines (Golden, CO)
- Energy Conversion Devices, Inc. (Troy, MI)
- Harvard University (Cambridge, MA)
- Iowa State University (Ames, IA)
- University of Oregon (Eugene, OR)
- Pennsylvania State University (University Park, PA)
- Syracuse University (Syracuse, NY)
- Univ. of California at Los Angeles (Los Angeles, CA)
- University of North Carolina (Chapel Hill, NC)
- University of Utah (Salt Lake City, UT)

Thin-Film Si R&D Partner Proposals
- MVSystems, Inc. (Golden, CO)

Special Topic Proposals (with EPRI)
- Institute of Energy Conversion (Newark, DE)
- Pennsylvania State University (University Park, PA)
- University of Illinois (Champagne, IL)
- University of South Florida (Tampa, FL)

Dissemination of research results is an important aspect of technology transfer. NREL researchers and subcontractors publish some 300 papers annually in scientific journals and conference proceedings. PV program and subcontractor reports are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161. For further information, contact Ann Hansen (303-384-6492).

Basol, B.; Kapur, V.; Leidholm, C.; Halani, A.; Norsworthy, G. *Application of CIS to High-Efficiency PV Module Fabrication: Annual Technical Progress Report, 1 Apr 1996-31 Mar 1997*. Aug 1997; 32 pp. Work by ISET, Inglewood, CA. Report SR-520-23444.

Compaan, A.D.; Bohn, R.G.; Contreras-Puente, G. *High-Efficiency Thin-Film CdTe PV Cells: Annual Technical Report, 20 Jan 1996-19 Jan 1997*. Aug 1997; 43 pp. Work by Univ. of Toledo, Toledo, OH. Report SR-520-23404.

Dalal, V.L.; Kaushal, S.; Han, K.; Girvan, R.; Knox, R.; Martin, F.; Hariasra, S.; Ping, E.; Xu, J.; Sipahi, L. *Comprehensive Research on Stability of a-Si and Alloy Materials and Devices: Annual Report, 31 May 1995-30 May 1996*. Aug 1997; 34 pp. Work by Iowa State Univ., Ames, IA. Report SR-520-23421.

Freitas, C. *Development of a Modular, Bi-Directional Power Inverter for PV Applications: Annual Technical Progress Report, Aug 1995-Aug 1996*. Aug 1997; 30 pp. Work by Trace Engineering Company, Inc., Arlington, WA. Report SR-520-23401.

Gregg, B.A. "Photoelectrochromic Cells and Their Applications." *Endeavour.* 1997; 21(2): pp. 52-55.

Gregg, B.A.; Sprague, J.; Peterson, M.W. "Long-Range Singlet Energy Transfer in Perylene Bis(phenethylimide) Films." *J. Physical Chemistry B*. 1997; 101(27): pp. 5362-5369.

Hoff, T.E. *Integrating Renewable Energy Technologies in the Electric Supply Industry: A Risk Management Approach*. July 1997; 82 pp. Work by Pacific Energy Group, Walnut Creek, CA. Report SR-520-23089.

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University Corner

The first planning meeting for "Sunrayce 99" was held at NREL on October 30, 1997. Participants included **Brian Castelli, Pat Booher**, and **Cathy Short (DOE)**; **Bob Noun, George Douglas**, and **Byron Stafford (NREL)**; **Syl Morgan-Smith (MRI)**; **Sarah Manion (DOE-Golden Field Office)**; **Mike White (Electronic Data Systems)**; **Jerry Wilson (General Motors)**; **Dan Eberle (New Resources Group)**; **Art Boyt (Crowder College)**; and **Byran Arnold (TRIO)**. Castelli and Booher expressed their happiness with Sunrayce 97 and their commitment to Sunrayce 99. A Memorandum of Understanding will detail the exact roles of DOE, GM, and EDS. An East Coast route is being evaluated for June 1999, with a test run with solar cars planned for June 1998. A workshop for students will be held in the Spring of 1998, probably in Atlanta. Contact: **Byron Stafford, 303-384-6426**

Texas Southern University (TSU, Houston, TX), funded by **NREL's PV Historically Black Colleges and Universities program**, had a 4-week summer camp for inner-city high school students to learn about Renewable Energy and Environmental Protection (REEP).

Recently, at **Port Elizabeth Technikon** in Port Elizabeth, South Africa, 15 African-American high school students from TSU's REEP program learned how to install and maintain PV systems. The students were guided by TSU staff and by NREL PV research associates from NREL-funded HBCUs, Texas Southern University, **Central State University**, and **Wilberforce University** (both in Wilberforce, Ohio). Contact: **Robert McConnell, 303-384-6419**

The **Reliability Team of the CdTe National Team** has completed the first phase of stressing cells made with many different back-contact recipes. A recent test with 13 samples was conducted at **Colorado State University** (CSU, Ft. Collins, CO) by **J. Sites** and others. Various back contacts were made on **Golden Photon, Inc.**, or **Solar Cells Inc.**, CdTe substrates finished through the CdCl treatment. The times to failure varied from hours to months; back barrier formation was the most common failure mode. Two issues are of concern: whether the 95°C temperature is too high a stress temperature, and what the source is of this failure mode. Contact: **Tom McMahon, 303-384-6762**

Mary Anderberg, Afshin Andreas, and **Martin Rymes** in **NREL's Center for Renewable Energy Resources** have made available the solar irradiance data from the **Historically Black Colleges and Universities (HBCU) Solar Radiation Monitoring Network**. The HBCU network operated from November 1985 through December 1996 and included six sites in the southeast United States. Quality-assessed data, monthly summaries, and plots may be accessed through NREL's Renewable Resource Data Center (RReDC) at http://rredc.nrel.gov/solar/old_data/hbcu. Contact: **Mary Anderberg, 303-275-4680**

Publications, Continued from p. 9

McConnell, R.D., ed. *Future Generation Photovoltaic Technologies—First NREL Conference. March 1997, Denver, Colorado. AIP Conference Proceedings 404,* Woodbury, New York: American Institute of Physics, 1997; 439 pp.

Molenbroek, E.C.; Mahan, A.H.; Gallagher, A. "Mechanisms Influencing 'Hot-Wire' Deposition of Hydrogenated Amorphous Silicon." *J. Applied Physics*. 15 August 1997; 82(4): pp. 1909-1917.

Russell, M.C.; Handleman, C.K.P. *SunSine300 AC Module: Annual Report, 25 July 1995-31 Dec 1996*. August 1997; 31 pp. Work by Ascension Technology, Inc., Waltham, MA. Report SR-520-23432.

Sasala, R.; Powell, R.; Dorer, G. *Technology Support for Initiation of High-Throughput Processing of Thin-Film CdTe PV Modules: Phase II Technical Report, 14 Mar 1996-13 Mar 1997*. Sept 1997; 35 pp. Work by Solar Cells, Inc., Toledo, OH. Report SR-520-23542.

Sopori, B.L., ed. *Seventh Workshop on the Role of Impurities and Defects in Silicon Device Processing: Extended Abstracts and Papers from the Workshop, 11-13 August 1997; Vail, Colorado*. Aug 1997; 250 pp.

Strawn, N.; Hicks, A.; Gwinner, D. *NREL International Programs*. September 1997, NREL/BR-520-23256; 8 pp.

Webb, J.D.; Moutinho, H.R.; Kazmerski, L.L.; Mueller, C.H.; Rivkin, T.V.; Treece, R.E.; Dalberth, M.; Rogers, C.T. "Infrared Spectroscopic, X-ray and Nanoscale Characterization of Strontium Titanate Thin Films." *Integrated Ferroelectrics*. Proceedings of the 8th International Symposium on Integrated Ferroelectrics, 18-20 March 1996, Tempe, Arizona. 1997; 15(1-4): pp. 9-18.

Wesley, A.; Wills, R. *Next-Generation 3-Phase Inverters: Phase 1 Annual Report, 1966*. July 1997; 40 pp. Work by Advanced Energy Systems Inc., Wilton, NH. Report SR-520-23330.

Witt, C.E.; Al-Jassim, M.; Gee, J.M., eds. *NREL/SNL Photovoltaics Program Review: Proceedings of the 14th Conference, 18-22 November 1996, Lakewood, Colorado. AIP Conference Proceedings 394*. Woodbury, NY: Amer. Inst. Physics, 1997; 940 pp.

Industry Updates, Continued from p. 8

for a manufacturing and systems workshop. Contacts: **Holly Thomas, 303-384-6400, NREL; Ward Bower, 505-833-5206, SNL**

In the recently completed second phase of the funds-in CRADA between **EBARA Solar, Inc.**, and **NREL's Crystal Growth and Devices Team (Tihu Wang, Tim Bekkedahl, Rebecca Nickell**, and **Ted Ciszek**), the focus was on silicon melt dynamics and dendritic silicon web ribbon crystal growth. An ESI production web furnace was set up at NREL to study liquid silicon behavior at 1400°-1500°C in the specially designed, shallow crucibles used for dendritic web growth from supercooled melts. NREL researchers have tested several design changes that achieve a more stable melt and increase the repeatability and reliability of the dendritic web growth process. This joint work has also greatly improved a start-up procedure for initiating growth of the thin-ribbon crystals. A third phase of the work began on November 1 and extends the CRADA activities to March 31, 1998. Contact: **Ted Ciszek, 303-384-6569**

Under a work-for-others contract initiated in July 1997, the **NREL's CIS team** has been engaged in the technology transfer of fabricating CIGS-based devices to **Optical Coating Laboratory, Inc. (OCLI)**, Santa Rosa, CA, for scale-up development. Since July, OCLI has demonstrated the fabrication of a monolithically integrated submodule (15.6 cm^2) with NREL-verified efficiency of 8.3%. They have also demonstrated a 14.7%-efficient laboratory-size solar cell of the same structure. This submodule was fabricated from a 12"x10.5" substrate with non-uniformity variation less than 2%. This progress is remarkable and reflects the commitment of the OCLI team to validate a manufacturing process rapidly, and the soundness of NREL's CIS fabrication process. Contacts: **Rommel Noufi, 303-384-6510, NREL; Gordon Matthew, 707-525-7984, OCLI**

NREL's John Pern, Steve Glick, and **Roland Hulstrom** have set up three DSET tabletop exposure systems and different exposure conditions that will be used to perform accelerated exposure testing for **Spire**'s (Bedford, MA) eight encapsulated ultralight c-Si solar cells, **Iowa Thin Film**'s (Boone, IA) four a-Si minimodules, and **Evergreen Solar**'s (Waltham, MA) 12 samples of new encapsulant laminated between two borosilicate plates. The 24 samples are being baseline characterized with various spectroscopic and I-V measurements. This work is a good example of how NREL's expertise in the processing, testing, and analysis of EVA encapsulants can effectively help the PV industry in a timely manner and can meet their needs in developing module manufacturing processes. Contacts: **John Pern, 303-384-6615, NREL; M. Nowlan, 617-275-6000, Spire; B. Scandrett, 515-292-7606, Iowa Thin Film**

Under a recently signed CRADA, **NREL's Amorphous Silicon Team**, which includes **Q. Wang** and **R. Crandall**, is collaborating with **Solarex Corp's Dave Carlson** to study light-induced metastability in a-Si:H devices. Light-induced metastability limits the efficiency of a-Si:H, so its understanding and eradication is a priority. Solarex recently discovered a new phenomenon: high-intensity light contributes to the annealing of light-induced metastability under reverse-bias in their devices. As part of the CRADA, Solarex asked the NREL team to apply its metastability and measurement expertise to the study of the phenomenon. Using both NREL- and Solarex-grown a-Si:H p-i-n solar cells, NREL has successfully reproduced the effect seen by Solarex. Contact: **Richard Crandall, 303-384-6676**

On October 30-31, PV managers from **NREL** and **DOE** visited **United Solar** and **Energy Conversion Devices**, Troy, MI; **Solar Cells, Inc.**, Toledo, OH; and the **University of Toledo**, Toledo, OH. In Troy, they saw the 5-MW roll-to-roll manufacturing of triple-junction a-Si. ECD and United Solar are already discussing plans for scale-up to the 50-100-MW level. At SCI, the managers saw SCI's high-rate CdS/CdTe deposition reactor, capable of depositing active semiconductor layers in under 1 minute. Manufacturing costs are projected at under $1/W at 25-MW levels, decreasing further as SCI scales up to more than 100 MW.

Detroit Edison has expressed an interest in photovoltaics, in terms of potential investment or joint ventures. Detroit Edison's **Ananth Ananthasubramaniam** and colleague **Norm Stevens** visited NREL to be introduced to PV technologies. Contact: **Ken Zweibel, 303-384-6441**

In November, **Vincent Capozzi** and **Eric Brambani** of **Schott Corp.**, visited NREL to discuss the potential use of their new, potentially lower-cost, "borofloat" glass, which has higher transmission and better robustness at high temperature than normal low-cost soda-lime float glass. However, borofloat is not yet as inexpensive as soda-lime glass, because it is not made in the same volume. **NREL's H. Branz, R. Noufi**, and **P. Sheldon** took part in the discussions and are making efforts to prove the new glass in thin-film cells. Meanwhile, Schott will be talking with various PV companies, including **Solarex** (a-Si), **Solar Cells Inc.** (CdTe), and **OCLI** (CIGS). Contact: **Ken Zweibel, 303-384-6441**

PV Calendar

March 21–25, 1998, *3rd International Conference of Solar Electricity: PV and Solar Thermal Technologies*. Sponsors: Government of Sharjah, NREL, others. Location: Sharjah, UAE. Contact: Fuad Abulfotuh, NREL. Phone: 303-384-6601 Fax: 303-384-6604.

April 25–30, 1998, *SolTech98*. Sponsor: SEIA/UPVG. Location: Orlando, Florida. Contact: UPVG. Phone: 202-857-0898 Fax: 202-223-5537.

June 1998, *PV Standards and Codes Forum*. Sponsor: NREL. Location: Winter Park, CO. Contact: Dick DeBlasio. Phone: 303-384-6452.

June 13–18, 1998, *Solar '98: Renewable Energy for the Americas*. Sponsor: ASES. Location: Albuquerque, NM. Contact: ASES. Phone: 303-443-3130 Fax: 303-443-3212.

July 6–10, 1998, *2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion*. Sponsor: WIP. Location: Vienna, Austria. Contact: WIP. Phone: +49-89-7201235 Fax: +49-89-7201291.

September 8–11, 1998, *15th NREL/SNL PV Program Review Meeting*. Sponsors: NREL, SNL. Location: Denver, CO. Contact: Mowafak Al-Jassim. Phone: 303-384-6602.

September 20–25, 1998, *1998 World Renewable Energy Congress V*. Sponsor: UNESCO and others. Location: Florence, Italy. Contact: A.A.M. Sayigh. Phone: +44-0118-961-1364 Fax: 44-0118-961-1365.

October 12–14, 1998, *4th Conference on Thermophotovoltaic Generation of Electricity*. Sponsor: NREL. Location: Denver, CO. Contact: Tim Coutts. Phone: 303-384-6561.

November 1998, *PV Performance and Reliability Workshop*. Sponsor: FSEC. Location: Cocoa, FL. Contact: Dick DeBlasio. Phone: 303-384-6452.

November 19–21, 1998, *ENERGEX '98—The 7th International Energy Conference and Exhibition*. Sponsor: University of Bahrain. Location: Manama, Bahrain. Contact: Dr. W.E. Alnaser. Phone: +973-688381 Fax: +973-688396.

Fall 1998, *Village Power '98*. Sponsor: NREL. Location: Washington, D.C. Contact: Roger Taylor. Phone: 303-384-6432.

This quarterly report encourages cooperative R&D by providing the U.S. PV industry with information on activities and capabilities of the laboratories and researchers at NREL.

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